Magnetization Dynamics

Why is this important today?

1. **Changing the direction of magnetization** is a key element in present technologies such as magnetic recording or electric transformers.

2. **The dynamics of itinerant ferromagnets at the femtosecond (10^{-15} sec) time scale** is the most challenging issue in today's magnetism, with impact on the future of magnetic recording and spin electronics.

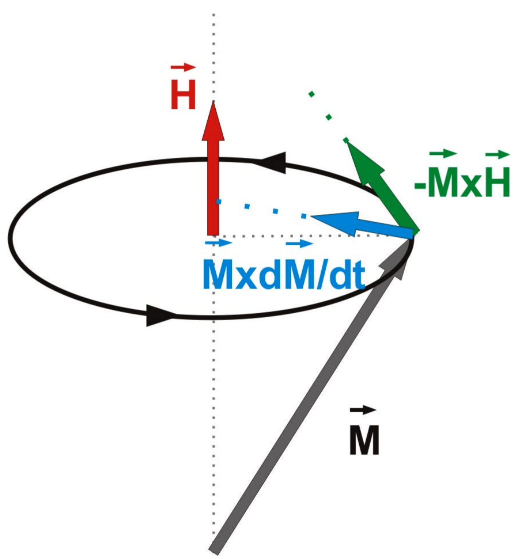
3. **Injection of spin polarized electrons** into a ferromagnetic metal is a promising new concept to excite or reverse the magnetization in small structures. The application depends on detailed. understanding of magnetization dynamics in metals and at interfaces.

Contents

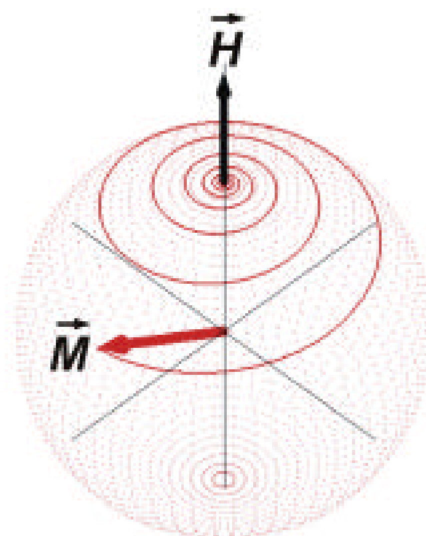
Landau-Lifschitz-Gilbert equation:

$$\frac{1}{\gamma}\frac{d\vec{M}}{dt} = \boxed{-\vec{M}\times\vec{H}} + \frac{1}{\gamma}\frac{\boxed{\alpha}}{\left|\vec{M}\right|}\left(\vec{M}\times\frac{d\vec{M}}{dt}\right)$$

Angular momentum change | Precession torque | Gilbert damping torque

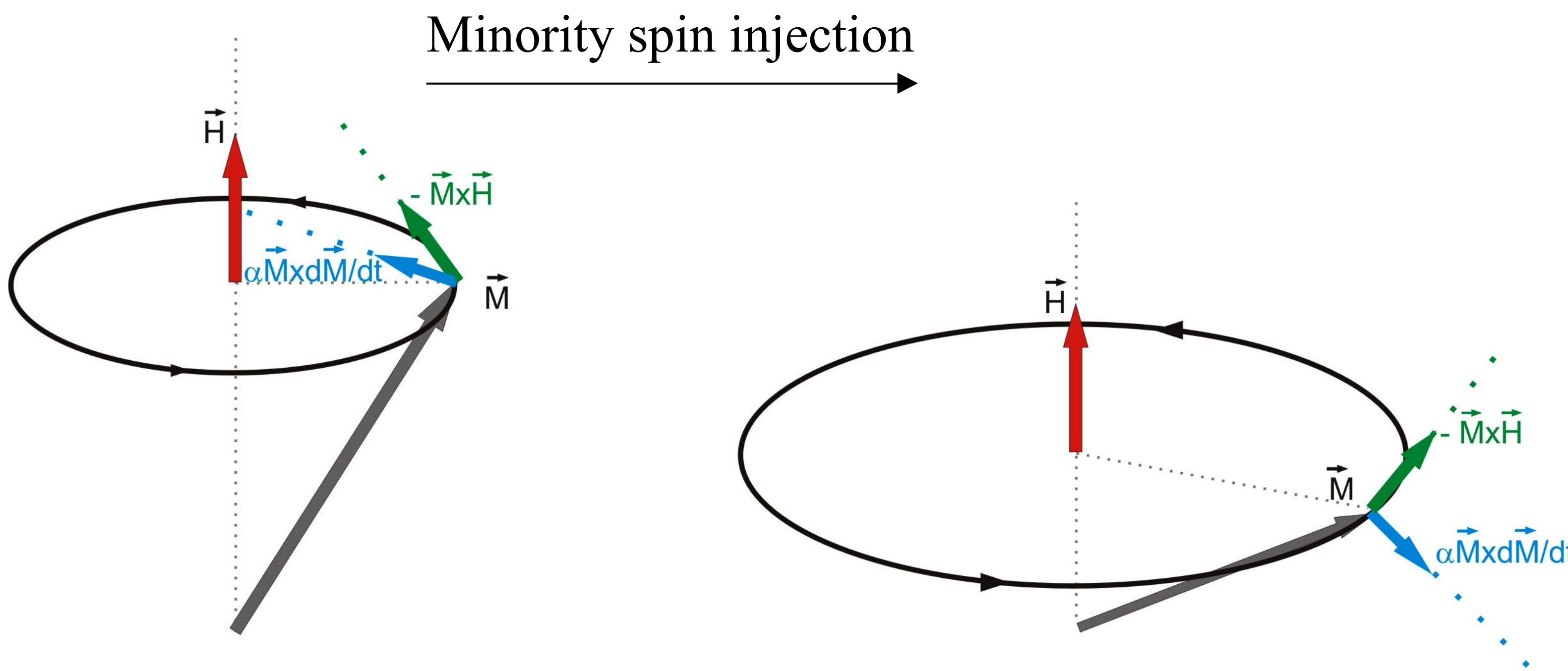


Direction of Torques

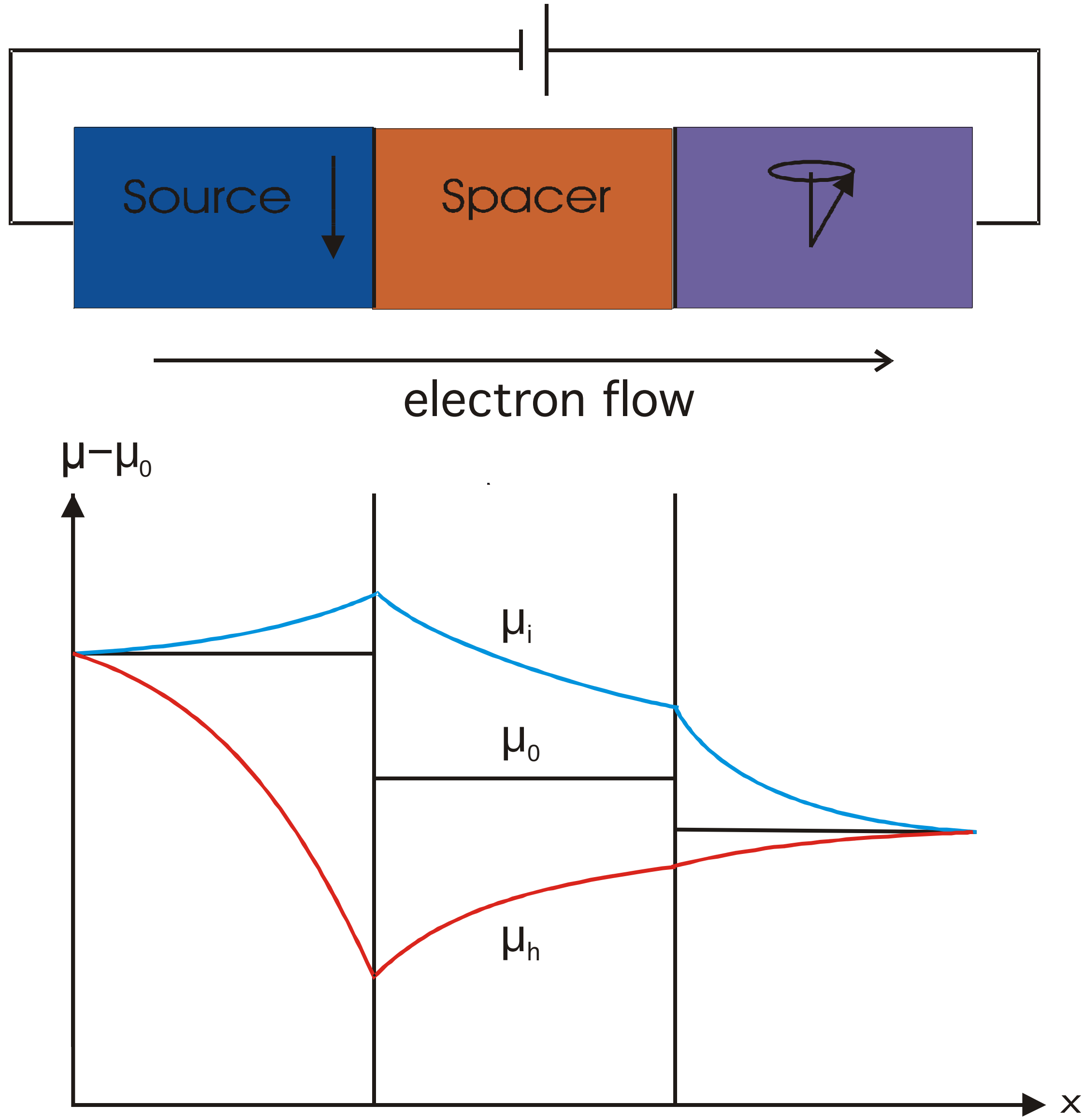


Motion of **M**

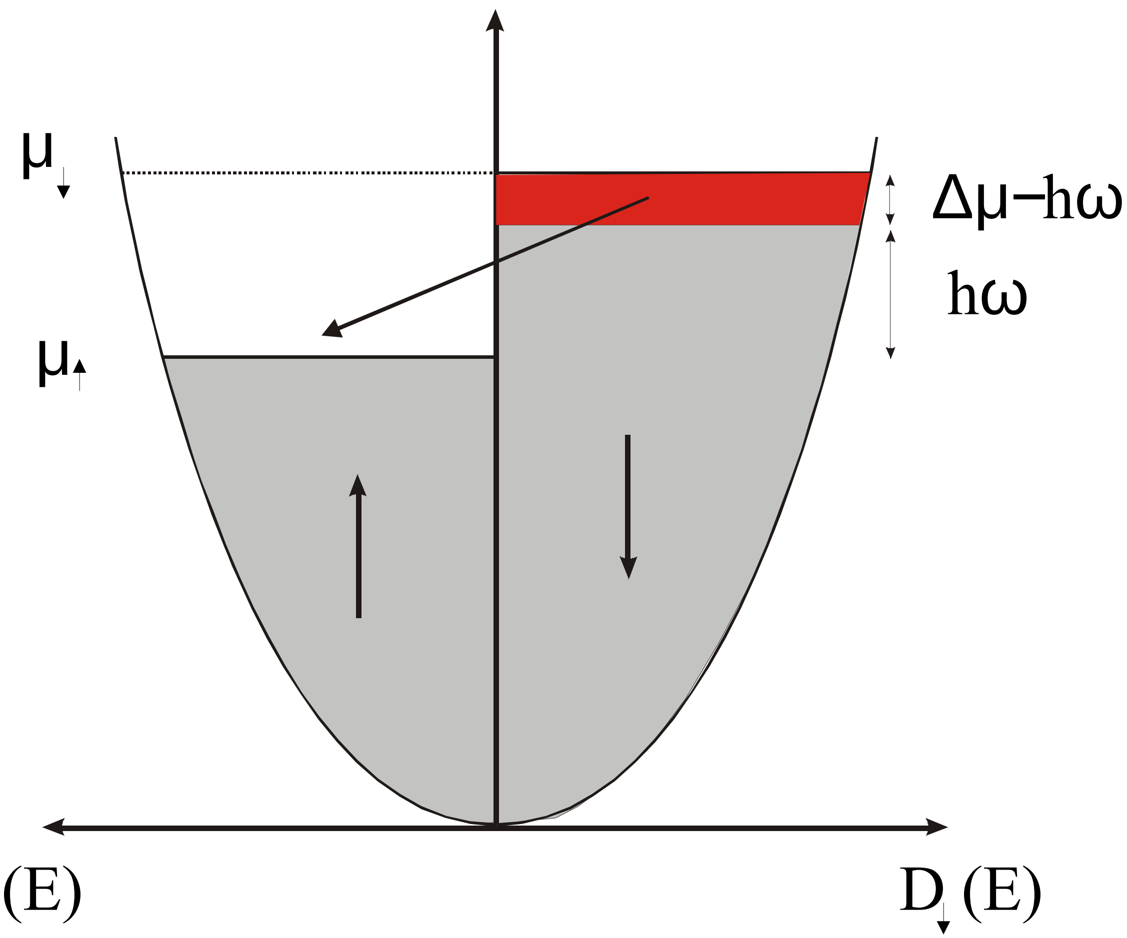
Negative Damping by Spin Injection



Spin Injection



Stimulated Emission of Spinwaves

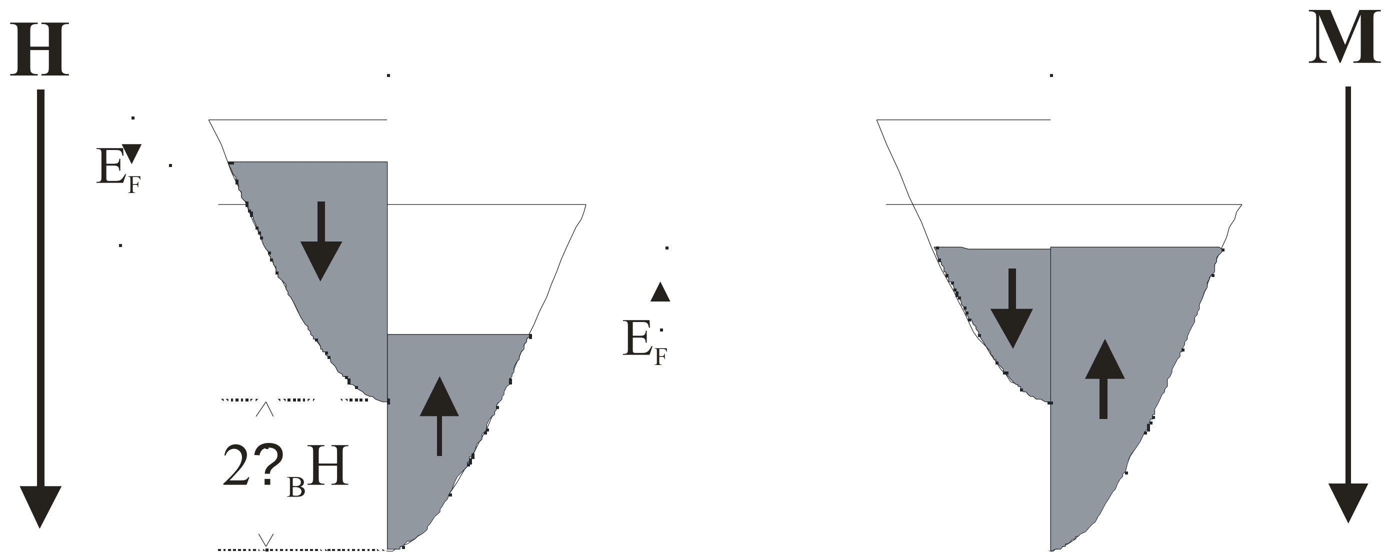


Interface damping τ_{GS}

(adapted from L. Berger)

$$\tau_{GS} = \alpha_S(\theta)(\Delta\mu + \hbar\omega)\frac{\vec{S} \leftrightarrow (\vec{u}_H \leftrightarrow \vec{S})}{\hbar S}$$

Paramagnetic metal



Immediately after application of a magnetic field

After a “long” time in the field

Switching time scales: ù = e/m.B

Precessional Torque

T_s = 10 psec at 1 Tesla

Angular momentum is transferred to source of magnetic field

Damping Torque

$T_d > T_s$ (typically $T_d = 10\ T_s$)

Angular momentum is transferred to solid

Time scale of various processes,
(leading to spin lattice relaxation)

Stoner excitation: 10^{-15} sec (Femtosec)

Emission of a spin wave : 10^{-12} sec (Picosec)

Absoption of spin waves by the lattice: 10^{-10} sec

Birth of the Two-Current Model

(Mott and Jones)

The resistance of ferromagnetic metals shows an anomalous behaviour near the Curie temperature; the resistance of nickel measured by Gerlach† is shown in Fig. 98.

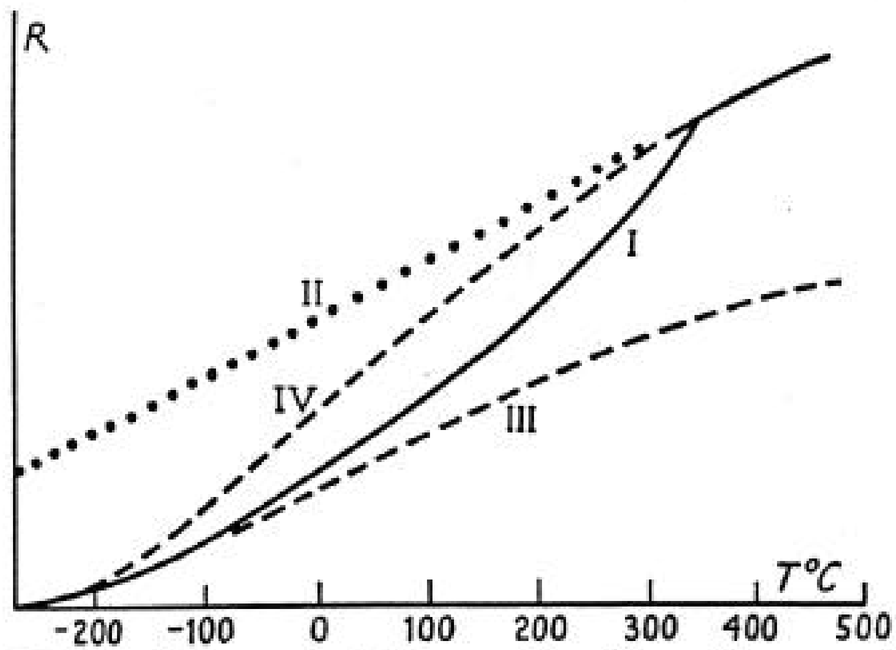


FIG. 98. Resistance of nickel as a function of temperature.
I. Observed.
II. Extrapolation of I.
III. Suggested theoretical curve for ferromagnetic nickel.
IV. Suggested theoretical curve for paramagnetic nickel.

Key experiments for scattering and spin motion of electrons

1. Spin polarized threshold photoemission: sign of spin polarization P.

2. Spin polarization of low energy cascade electrons: enhancement of P

3. Spin polarized overlayer experiments: spin filtering and mean free paths

4. Inverse photoemission: spin polarization of hole states

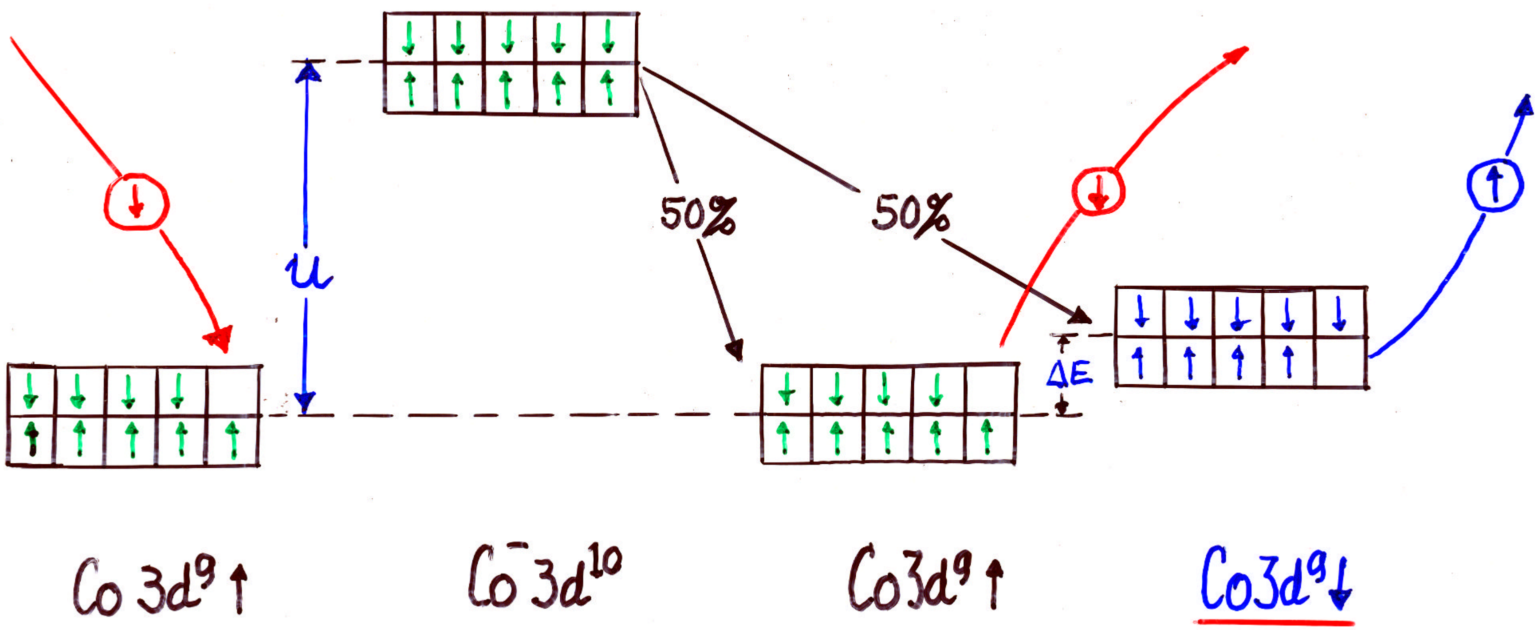
5. Two photon photoemission with femtosec. laserpulses: spin dependend lifetimes of electrons

6. Tunneling from ferromagnetic tip into vacuum and into GaAs: contribution of s- and d- states

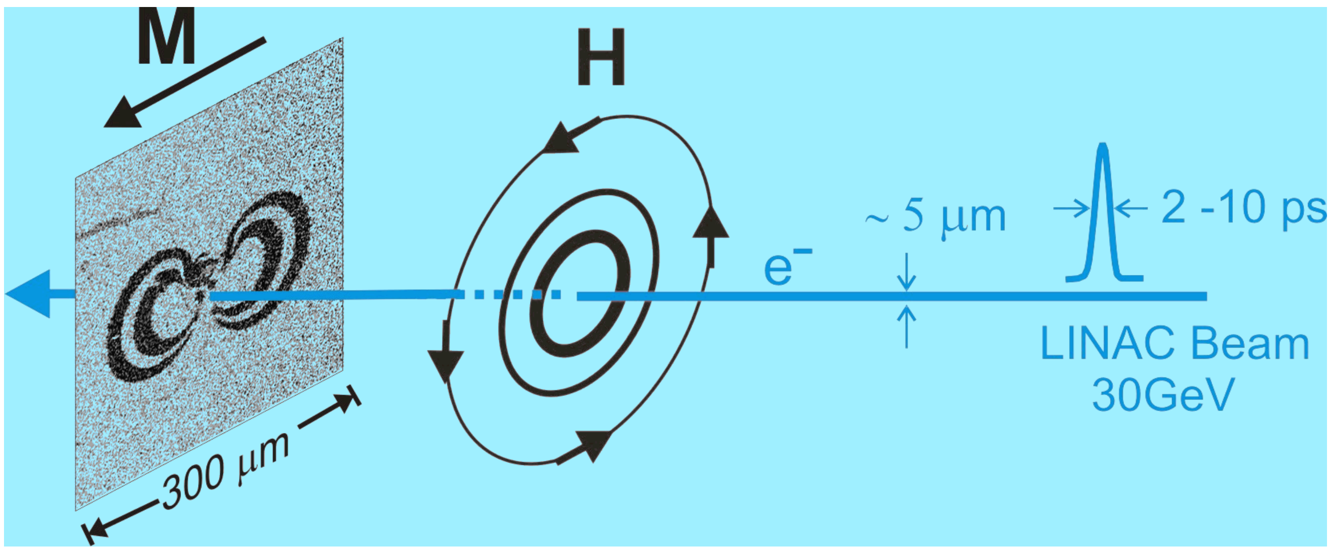
7. Spin polarized electron transmission and reflection: spin motion

Stoner Excitations:

Changing the Magnetization by Electron Scattering

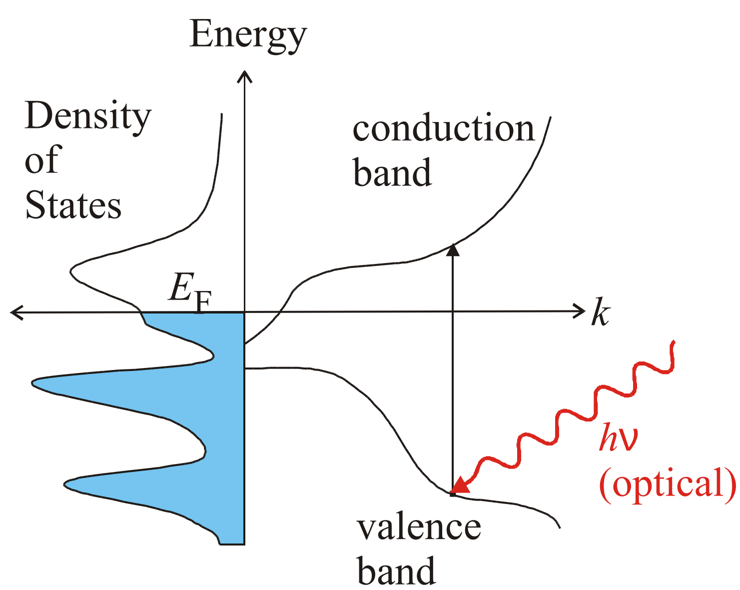


Principle of the experiment with the Stanford Linear Accelerator



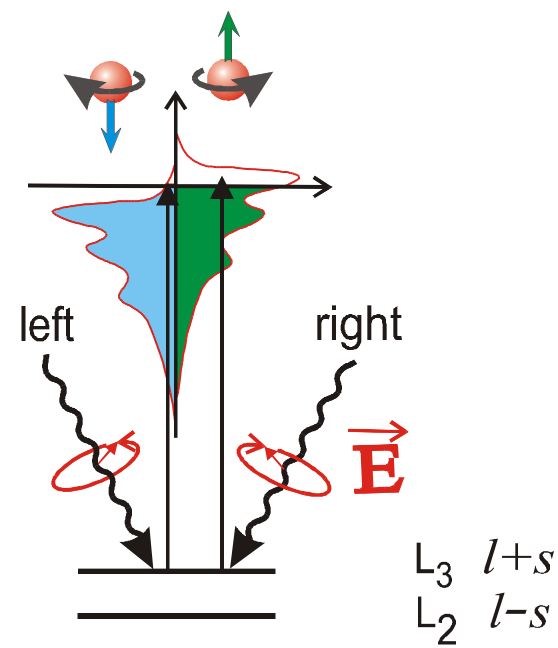
Why X-Rays?

Faraday and Kerr effect



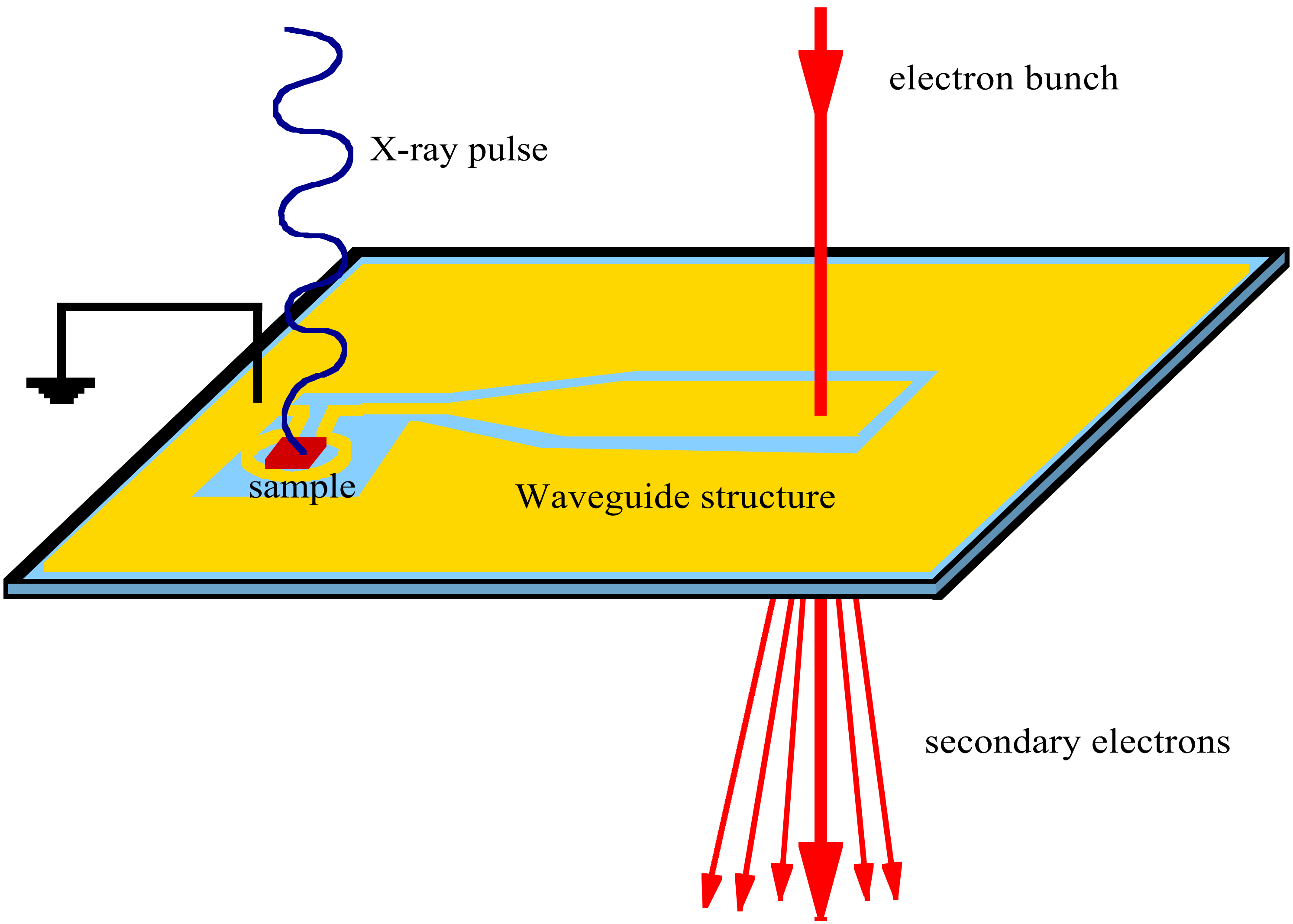
Magneto-optical response depends on
k-dependent band structure

X-ray Magnetic Dichroism



X-Ray response depends on k-integrated quantities:
number of holes, spin monent, orbital moment

Ultrafast Current Pulse Generation by an Electron Bunch



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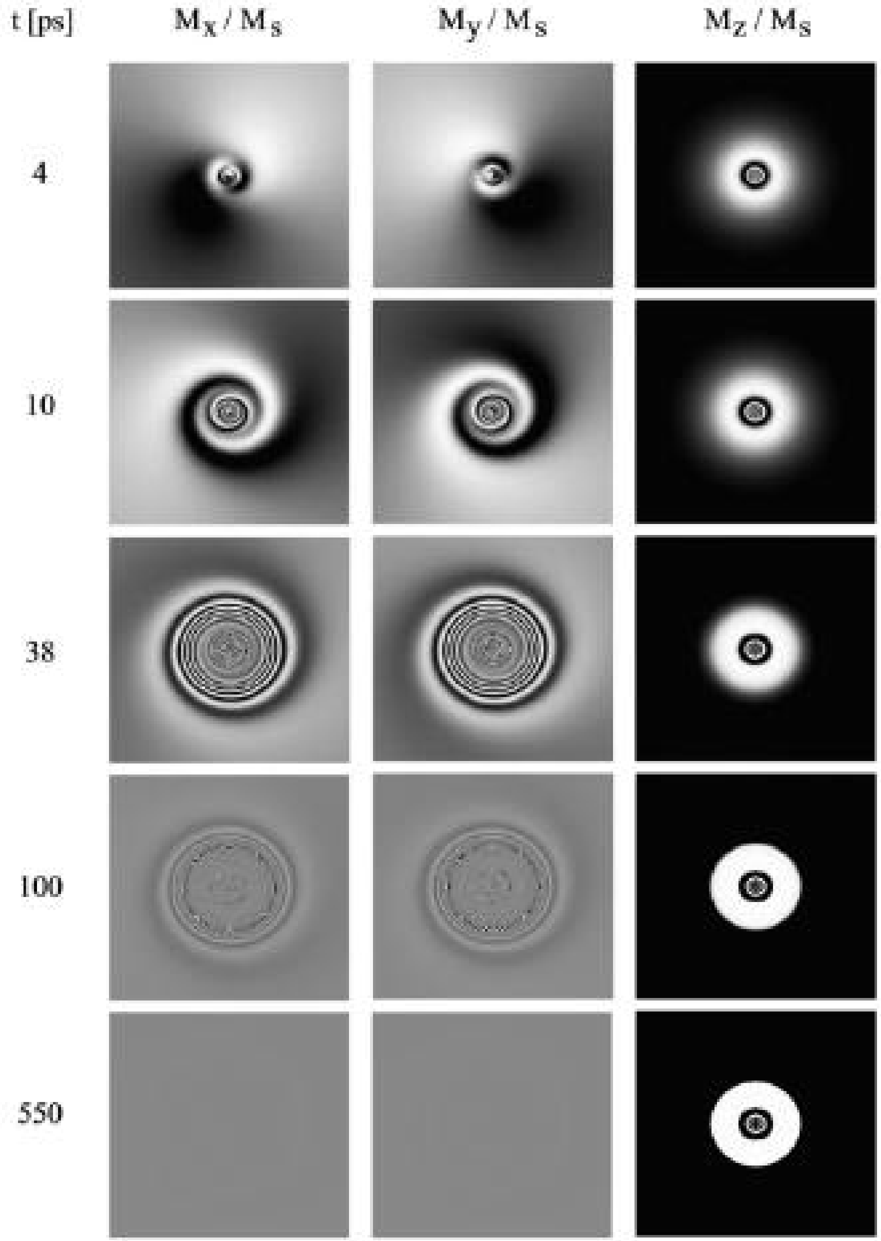

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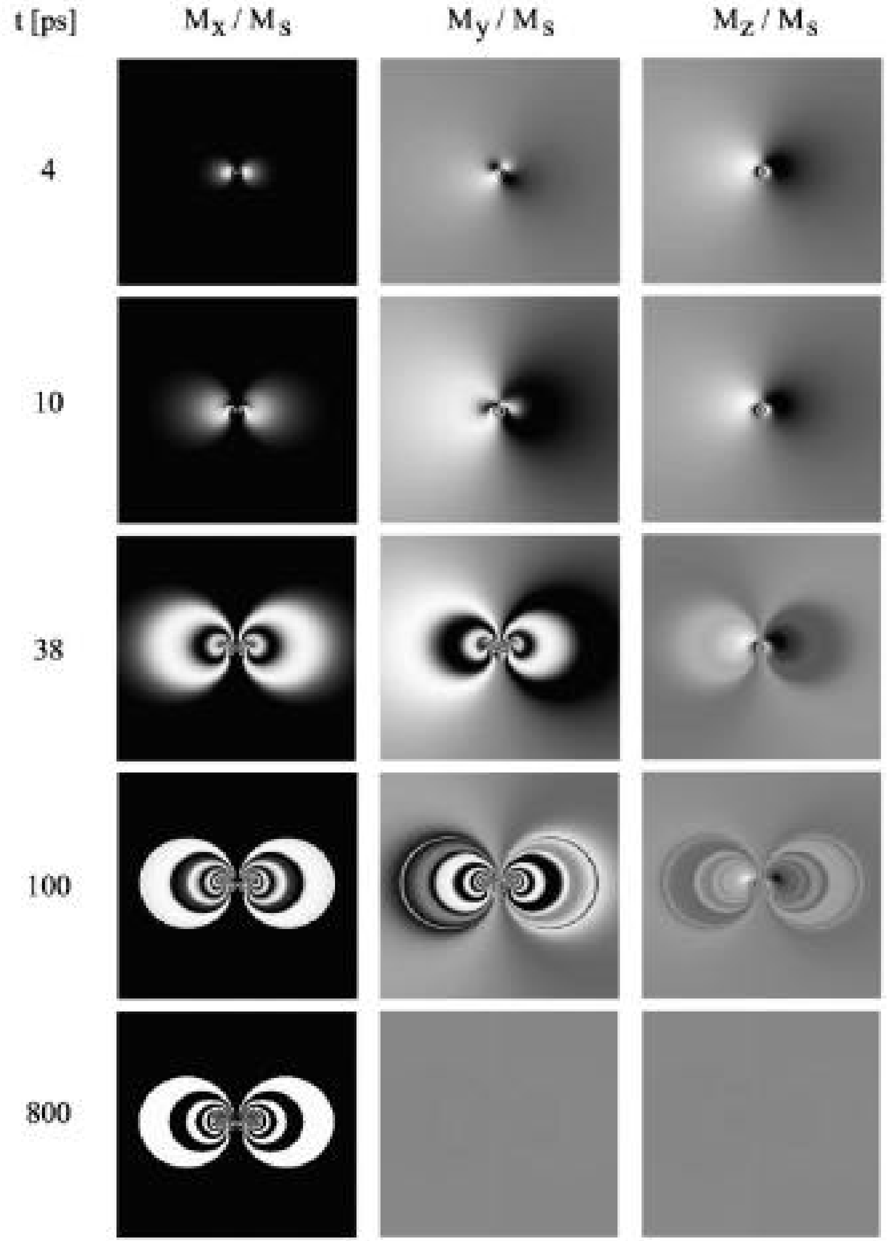

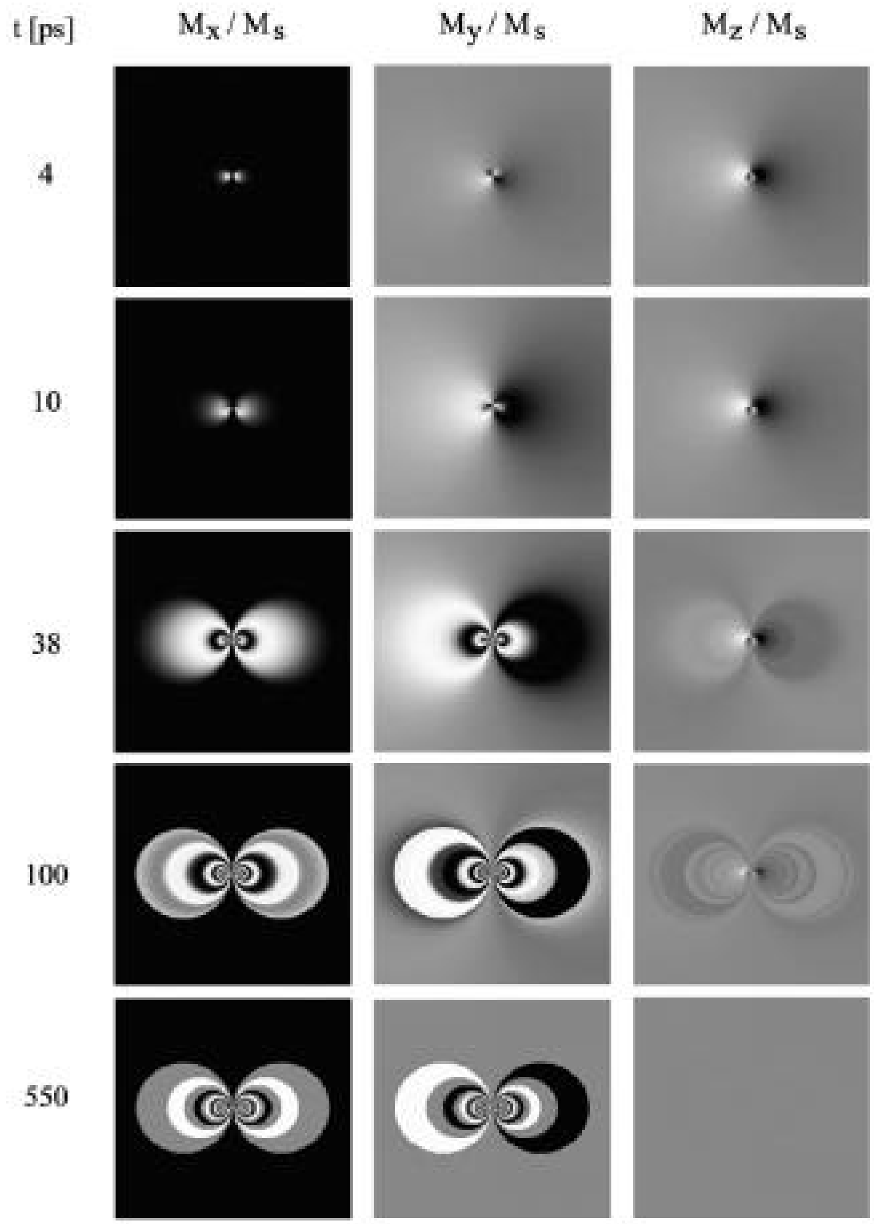
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M_x / M_s
M_y / M_s
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4
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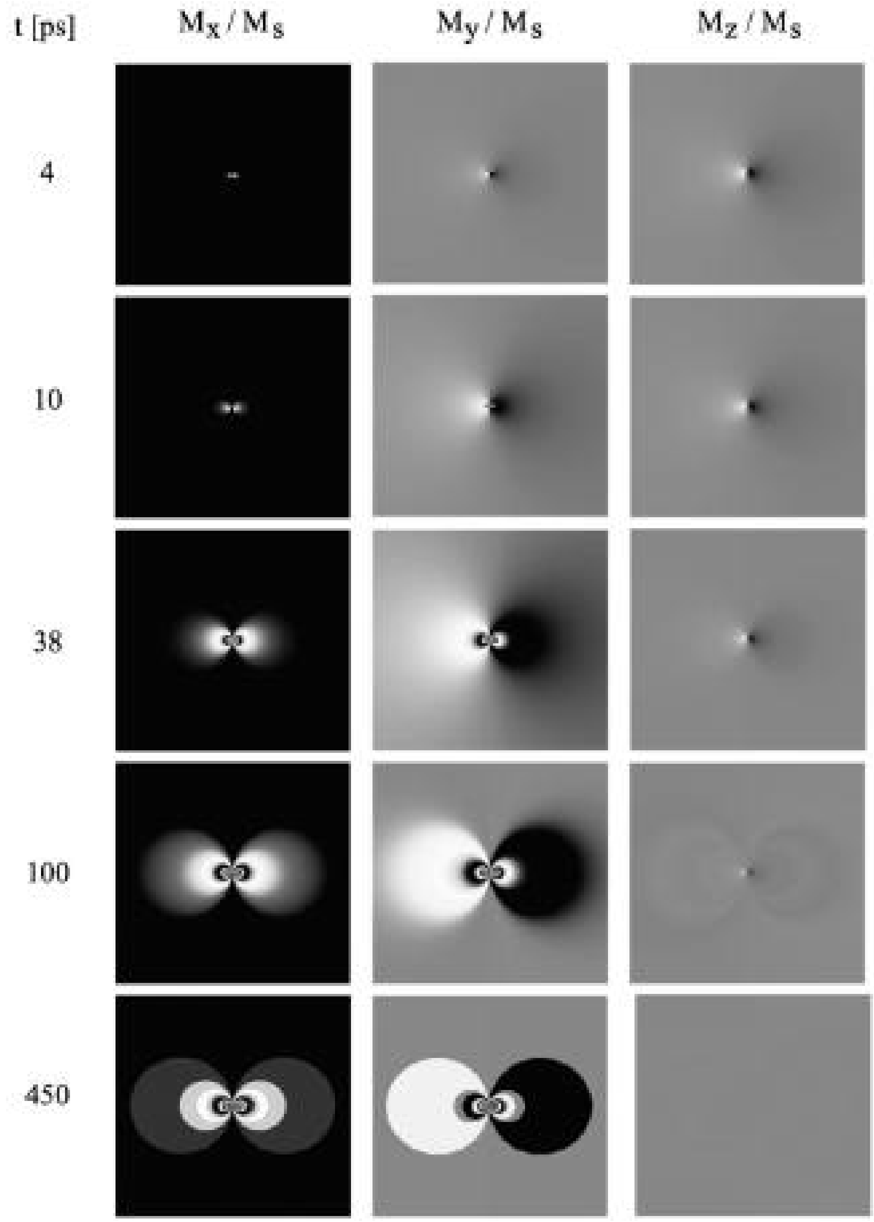
38
100
550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